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USE OF TWO INDIRECT METHODS FOR THE DETERMINATION OF THE HYGROSCOPIC COEFFICIENTS OF SOILS [1]

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INTRODUCTION

The relative advantages and disadvantages of the moisture-equivalent method for the indirect determination of the hygroscopic coefficients of soils have been discussed in a previous article (3).[2] While in connection with soil-survey reports the moisture equivalents may conveniently be used to indicate the relative fineness of texture as a single-valued expression,[3] even the determination of these consumes far more time than is desirable in connection with many soil studies.

A very simple, rapid method seemed to be offered by a formula derived by Briggs and Shantz (4, p. 66) for the estimation of the hygroscopic coefficient from the maximum water capacity, as determined by Hilgard's method. Such an indirect method would prove extremely useful if it could be relied upon to give results in at least fair accord with those obtained by direct determination. The determination of the maximum water capacity by Hilgard's method requires only very simple apparatus, consumes but little time, and can be carried out in the most poorly equipped laboratory and doubtless even in an ordinary farm kitchen (14). To test the reliability of this proposed method, we have made determinations of the water capacity of 53 soils of which the hygroscopic coefficients had previously been carefully determined.

[1] The work reported in this paper was carried out in 1912 at the Nebraska Agricultural Experiment Station, where the authors were, respectively, Chemist and Assistant in Chemistry.

[2] Reference is made by number to "Literature cited," p. 359.

[3] The advantages of such a single-valued expression of the "different degrees of 'heaviness' of soils" (7, p. 440) appears to have first been suggested by Hilgard in connection with his introduction of the determination of the hygroscopic coefficient (6, p. xi).

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A method which will give results sufficiently reliable and accurate for many purposes, such as soil surveys, and yet be far more simple even than the preceding and more economical of time where any very large number of samples is to be handled, seems capable of development. This method would be an indirect one based upon the determination of the hygroscopic moisture in air-dried samples. As our work on this was interrupted several years ago by the removal from Nebraska first of the junior author and later of the senior author and there appears little probability of either of them being able to continue the work, at least for some time, the results are reported in the hope that in some other laboratory the limitations of the method may soon be determined.

HISTORICAL REVIEW

Hilgard's method for the determination of the maximum water capacity first proposed in 1893 (8, p. 256; 9, p. 74) has later been described in various publications (12, p. 82; 10, p. 15; 11, p. 209). From a comparison of the hygroscopic coefficient with the wilting coefficient in the case of a series of 17 soils and of the maximum water capacity with the wilting coefficient in the case of another series of some 15 soils Briggs and Shantz (4) have derived the formula:

$$\text{Hygroscopic coefficient} = (\text{maximum water capacity} - 21) \times 0.234$$

Unfortunately only four of the samples appear in both series. The data on these are reported in Table I. The calculated values agree fairly satisfactorily with those directly determined.

TABLE I.—*Relation of the maximum water capacity to the hygroscopic coefficient as found by Briggs and Shantz*

Soil No.	Type of soil.	Maximum water capacity.	Hygroscopic coefficient.		Difference.
			Determined.	Calculated.	
7	Coarse sand	23.2	0.5	0.5	0.0
2	Fine sand	29.9	1.5	2.1	+ .6
8	do	28.5	2.3	1.7	− .6
9	do	31.4	2.3	2.4	+ .1

Briggs and Shantz appear to have overlooked the work of Loughridge (12), who, some 20 years previously, using some 40 California soils ranging in texture from clays to sands, made a critical study of the relation of both the maximum water capacity and the hygroscopic coefficient to the mechanical composition. In the case of all of these he determined the hygroscopic coefficient, the maximum water capacity, both by weight and by volume, and the mechanical composition. In the first three columns of Table II we give the portions of his data dealing with the present subject, arranging the soils in the order of their hygro-

scopic coefficients. In the fourth column are shown the hygroscopic coefficients calculated from the maximum water capacities by the Briggs-Shantz formula, and in the last the differences between these and the directly determined values. While with about half the soils there is a fair agreement, in the case of the others the divergence is so wide that the calculated values would be quite misleading as to the relative hygroscopicity.

TABLE II.—*Concordance of the determined hygroscopic coefficient with that calculated by the Briggs-Shantz formula from the maximum water capacity in the case of California soils reported by Loughridge*

Soil No.	Maximum water capacity.	Hygroscopic coefficient.		Departure.
		Determined.	Calculated.[a]	
6	54.9	14.53	7.93	−6.60
863	68.8	14.20	11.18	−3.02
188	59.6	13.70	9.03	−4.67
643	64.6	13.51	10.20	−3.31
1679	46.0	11.98	5.85	−6.13
68	59.8	11.19	9.08	−2.11
676	54.4	11.11	7.82	−3.29
77	68.9	10.38	11.21	.83
110	52.4	10.32	7.35	−2.97
67	50.7	10.26	6.95	−3.31
789	57.8	9.74	8.61	−1.13
506	55.6	9.26	8.10	−1.16
8	52.1	9.18	7.28	−1.90
10	82.3	9.18	14.34	5.16
1	63.5	7.52	9.95	2.43
1678	34.2	6.41	3.09	−3.32
1113	52.3	6.00	7.32	1.32
1115	53.8	5.93	7.68	1.75
1284	58.8	5.81	8.85	3.04
168	38.7	5.49	4.14	−1.35
1167	41.7	5.38	4.84	−.54
1645	58.4	5.27	8.75	3.48
4	46.6	5.18	5.99	.81
2	52.4	5.14	7.35	2.21
1647	49.9	5.14	6.76	−1.62
986	42.0	5.10	4.91	−.19
1663	48.0	5.06	6.32	1.26
586	47.3	4.86	6.15	1.29
1655	44.3	4.20	5.45	1.25
1159	37.4	4.00	3.84	−.16
1055	36.9	3.62	3.72	.10
1197	34.8	3.48	3.23	−.25
1148	41.5	3.43	4.80	1.37
51	49.5	3.17	6.70	3.53
9	58.9	2.63	8.87	6.24
130	40.7	2.30	4.61	2.31
1281	37.9	1.98	3.95	1.97
1147	28.7	1.84	1.80	−.04
1595	29.7	1.15	2.04	.89
233	23.0	.79	.47	−.32

[a] By the Briggs-Shantz formula: Hygroscopic coefficient = (maximum water capacity − 21) × 0.234.

Caldwell (5, p. 15) in connection with a study of the permanent wilting in plants has determined both the hygroscopic coefficients and the water capacities of "a very pure sand, an 'adobe' clay loam containing less than 0.1 per cent of humus, and nineteen artificial mixtures of these two soils varying by increments of 5 per cent of loam from 95 per cent sand with 5 per cent loam to 95 per cent loam with 5 per cent sand." The observed hygroscopic coefficients of the two soils were 2.41 and 7.51 and the corresponding values calculated from the water capacities 2.30 and 7.40, respectively. The calculated coefficients of the artificial mixtures agreed equally well with the directly determined values. Clearly the concordance is here well within the limits of experimental error; and if the same held true for a series of 21 natural soils with a range in hygroscopic coefficient from 2.5 to 7.5, this indirect method would leave little to be desired in respect to simplicity and reliability.

It must, however, be emphasized that such artificial mixtures can not take the place of natural soils in testing such a method, as, if a formula holds true on each of two components separately, it should hold equally true for all mixtures of these. Thus, to illustrate, in the case of the soils studied by Loughridge (12), No. 77 and 1147, with determined hygroscopic coefficients of 10.38 and 1.84 and calculated values of 11.21 and 1.80, respectively, might be employed to prepare artificial mixtures and all the latter should show water capacities such that the calculated hygroscopic coefficients should agree with those directly determined, while with similar mixtures of No. 643 and 51, with determined values of 13.51 and 3.17 and calculated values of 10.20 and 6.70, respectively, the intermediate mixtures should be expected to show a concordance, although neither of the two soils by itself did.

ESTIMATION OF THE HYGROSCOPIC COEFFICIENT FROM THE MAXIMUM WATER CAPACITY

The determinations of the maximum water capacity were made in triplicate or quadruplicate, the concordance of the determinations being shown in Table III.

TABLE III.—*Concordance of quadruplicate determination of the maximum water capacity*

Soil No.	Individual determinations.				Average.
	1	2	3	4	
A	60.5	60.8	61.8	63.0	61.5
B	62.2	62.3	62.5	63.7	62.7
C	72.9	73.4	73.1	74.7	73.5
D	61.5	62.3	63.4	61.9	62.2

In Table IV are reported the data on a series of 36 loess soils, including the maximum water capacity, the hygroscopic coefficient calculated from the preceding by the Briggs-Shantz formula, and the departure of the calculated from the determined value, previously reported (1, p. 216). The samples were collected from 30 virgin prairie fields in Nebraska, 5 near each of the 6 towns mentioned at the head of the columns. All were taken from fields classified by the Federal Bureau of Soils as "Marshall silt loam" or "Colby silt loam." In each field 10 borings were made to a depth of 6 feet and composite samples prepared of each foot section, thus giving 6 samples from each field. From these were prepared the samples used in this work, each of the latter being prepared by mixing equal weights of the corresponding five field samples (1, p. 204). Each value for the directly determined hygroscopic coefficients represents the average of 10 determinations (1, p. 214).

TABLE IV.—*Maximum water capacities of loess soils in Nebraska and the hygroscopic coefficients calculated from these by the Briggs-Shantz formula*

MAXIMUM WATER CAPACITY

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Foot.							
1	66.0	65.4	72.0	69.7	69.5	73.5	69.3
2	64.4	63.0	68.8	75.6	69.9	66.8	68.1
3	61.6	60.6	67.4	73.5	63.4	62.5	64.8
4	62.2	59.7	61.0	70.1	64.2	63.7	63.5
5	59.4	58.1	61.5	67.0	63.4	62.3	61.9
6	55.8	57.8	62.7	63.0	66.2	60.2	60.9
Average	61.6	60.8	65.6	69.8	66.1	64.8	64.8

CALCULATED HYGROSCOPIC COEFFICIENT

1	11.3	10.3	11.9	11.4	11.3	12.3	11.4
2	10.1	9.8	11.2	12.8	11.4	10.7	11.0
3	9.5	9.2	10.8	12.3	9.5	9.7	10.2
4	9.6	9.0	9.4	11.5	10.1	10.0	9.9
5	8.9	8.8	9.5	10.6	9.9	9.6	9.5
6	8.1	8.3	9.7	9.8	10.6	9.2	9.4
Average	9.6	9.2	10.4	11.4	10.5	10.2	10.2

DEPARTURE OF CALCULATED FROM DETERMINED HYGROSCOPIC COEFFICIENT

1	2.2	0.3	1.8	2.8	−0.7	0.2	1.1
2	.5	−1.1	.0	1.2	−3.0	−3.0	−.9
3	−.2	−1.5	−.5	−.1	−4.1	−4.2	−1.7
4	−.3	−.7	−.8	.4	−2.9	−3.0	−1.2
5	−.1	−.3	−.1	−.1	−2.9	−3.0	−1.1
6	−.2	−.8	.3	−.9	−2.1	−3.3	−1.2
Average	.3	−.7	.1	.5	−2.6	−2.8	−.8

In the case of rather more than half of the samples the calculated values agree satisfactorily with the directly determined hygroscopic coefficients. In the case of the Lincoln and Weeping Water samples, which are richest in clay and silt, and correspondingly poorest in very fine sand (2, p. 407), the calculated values are much too low for all except those samples from the surface foot. As an index of texture the calculated hygroscopic coefficients would be very misleading. For instance, the Wauneta samples, with an average of 9.6, would appear almost as fine-textured as the Weeping Water soils with an average of 10.2, whereas in fact actual mechanical analyses have shown the latter to contain nearly three times as much clay, more than half as much again silt, and only about one-fourth as much very fine sand (Table V). It is of interest that in the case of those members of this series with which satisfactory results are obtained by the Briggs-Shantz formula for the calculation of the hygroscopic coefficient from the mechanical analysis the formula of the same authors for the calculation of this value from the maximum water capacity fails, and vice versa.

TABLE V.—*Relation of calculated hygroscopic coefficients to the texture of Nebraska soils.*[a]

Item.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.
Maximum water capacity	*Per cent.* 61.6	*Per cent.* 60.8	*Per cent.* 65.6	*Per cent.* 69.8	*Per cent.* 66.1	*Per cent.* 64.8
Calculated hygroscopic coefficient	9.6	9.2	10.4	11.4	10.5	10.2
Determined hygroscopic coefficient	9.2	9.9	10.3	11.0	13.1	13.0
Gravel, above 1.0 mm.	.0	.0	.0	.0	.1	.0
Coarse sand, 1.0—0.5 mm.	.1	.1	.2	.2	.4	.2
Medium sand, 0.5—0.25 mm.	.3	.4	.3	.5	.7	.3
Fine sand, 0.25—0.10 mm.	1.9	1.5	1.3	1.9	2.4	1.2
Very fine sand, 0.10—0.05 mm.	49.3	38.6	27.9	21.6	10.3	12.7
Silt, 0.05—0.005 mm.	42.2	51.6	62.6	64.5	68.5	68.5
Clay, 0.005—0.000 mm.	6.3	7.8	7.7	11.3	17.6	17.3

[a] The mechanical analyses are from Alway and Rost (2, p. 407.)

The series of samples reported in Table VI includes, in addition to loess soils from Nebraska, residual soils from the same State and a few samples from the Southwestern States. The data upon both the hygroscopic coefficient and the water capacity are the means of five or more concordant determinations. The range in texture is much wider than that of those in Table IV and quite similar to that of the soils dealt with by Briggs and Shantz (4, p. 67). Except in a few cases, the calculated value agrees fairly well with the directly determined value. The widest departures are shown by the eastern Nebraska loess subsoil, similar in texture to the Lincoln and Weeping Water subsoils reported in Table IV and by two surface soils,

one from New Mexico and the other from Arizona. Three residual soils from Nebraska, No. 4, 5, and 6, which showed very similar hygroscopic coefficients, differ distinctly in water capacity.

TABLE VI.—*Comparison of the determined hygroscopic coefficient with that calculated from the maximum water capacity*

Soil No.	Description of soil.	Maximum water capacity.[a]	Hygroscopic coefficient.		
			Directly determined.[b]	Calculated from maximum water capacity.[c]	Departure of calculated coefficient from that found.
A	Dune sand, western Nebraska.....	25.8	0.6	1.1	0.5
1	Desert sand, Palm Springs, Cal.....	28.9	.9	1.9	1.0
2	Sandy subsoil, Palm Springs, Cal.....	27.0	1.1	1.4	.3
3	Desert sand, Orogrande, N. Mex.....	27.1	1.7	1.4	−.3
4	Sandy surface soil, western Nebraska..	34.2	3.3	3.1	−.2
5	Sandy subsoil, A, western Nebraska...	31.0	3.4	2.3	−1.1
6	Sandy subsoil, B, western Nebraska...	36.0	3.4	3.5	.1
7	Sandy loam subsoil, western Nebraska.	46.3	5.6	5.9	.3
8	Sandy loam surface, western Nebraska.	53.4	7.1	7.6	.5
9	Silt loam subsoil, A, western Nebraska.	57.2	7.6	8.5	.9
10	Silt loam subsoil, B, western Nebraska.	55.4	8.2	8.1	−.1
11	Red loam surface, Cuervo, N. Mex....	49.0	10.0	6.6	−3.4
12	Silt loam surface, A, western Nebraska.	56.8	10.1	8.4	−1.7
13	Silt loam surface, eastern Nebraska....	60.9	10.2	9.7	−.5
14	Silt loam surface, B, western Nebraska.	63.7	10.5	10.0	−.5
15	Adobe surface soil, McNeal, Ariz.....	60.3	12.9	9.0	−3.9
16	Silt loam subsoil, eastern Nebraska....	65.7	13.3	10.5	−2.8

[a] Determined by Mr. J. C. Russel.
[b] Determined by Mr. G. R. McDole.
[c] Using Briggs-Shantz formula: Hygroscopic coefficient=(maximum water capacity−21)×0.234.

Thus, while the Briggs-Shantz formula with many soils gives values fully in accord with those directly determined, with many others it gives results so widely divergent that it can not be regarded as sufficiently reliable for studies of available soil moisture, or even for soil-survey purposes.

ESTIMATION OF THE HYGROSCOPIC COEFFICIENT FROM THE HYGROSCOPIC MOISTURE

The hygroscopic coefficient indicates the maximum of hygroscopic moisture, the amount found when a more or less completely dried soil has been kept in contact with a saturated atmosphere at a constant temperature until the moisture in the soil is in approximate equilibrium with that in the atmosphere. Theoretically, actual equilibrium would not be attained until the moisture content of the soil equaled that of the same soil in actual contact with water (13, p. 448), but the time required for this is so great that this theoretical consideration does not affect the present discussion.

If two soils, A and B, be allowed in one case to reach equilibrium with a saturated atmosphere and the hygroscopic coefficients thus found be a and b, respectively, and in another case the same soils be allowed to reach

equilibrium with a partially saturated atmosphere, the amounts of hygroscopic water present in the latter case, a' and b', should bear the same relation to one another as do the hygroscopic coefficients—

$$\frac{b}{b'}=\frac{a}{a'} \text{ or } b=a\,\frac{b'}{a'}$$

If the soils can conveniently be brought into equilibrium with the partially saturated atmosphere, it would simply be necessary to determine accurately the hygroscopic coefficients of a few typical soils of which large quantities of thoroughly mixed, air-dried samples have been prepared and then expose to a partially saturated atmosphere portions of some of these along with the samples of which the hygroscopic coefficients are desired. From the found amounts of hygroscopic moisture the hygroscopic coefficients could be calculated by the above formula. This would obviate many of the inconveniences connected with the determination of hygroscopic coefficients, including the difficulty of obtaining a fully saturated atmosphere and of preventing dew formation through fluctuations of temperature.

As we had a series of foot samples of loess which had already been subjected to careful hygroscopic-coefficient determinations (1, p. 215–216), they were the first to be tried. The samples, after being brought from the fields in cloth sacks, had been stored for several months in the unheated but well-ventilated attic of the Nebraska Experiment Station building and later reduced to the desired degree of fineness, thoroughly mixed, placed in sealed jars, and again stored in the attic. About a year previous the moisture had been determined in some 50 of the field samples before preparing the composites and had been found to lie between the limits of 2.5 and 4.9, practically the same as found in this experiment. In shallow aluminum trays 5 by 7 inches with edges 0.75 inch high the samples were exposed in triplicate on the shelves of the attic storeroom mentioned above. Each tray carried about 10 gm. of soil. All the samples were exposed for seven days, those from Wauneta and McCook from March 15 to 22 and the others from March 25 to April 1. With the first set the range of temperature in the air of the room was 1° to 14° C.; and that of the humidity at the Lincoln (Nebr.) station of the Weather Bureau, 2 miles distant, was 67 to 94 per cent, while with the second the corresponding data were 9° to 23° C. and 42 to 93 per cent. Three of the samples which had been exposed in the first set were exposed again with the second and were found to have the same amount of hygroscopic moisture in both cases. Accordingly we may assume that all of the former contained the same amount of moisture that they would have shown if exposed with the second set, with which there were exposed in duplicate two soils, H and S, which had been repeatedly used as control soils in the determination of hygroscopic coefficients and for which, accordingly, we had a great many concordant determinations, the average of which was 5.6 for H and 22 for S. The

hygroscopic moisture is reported in Table VII. The triplicate determinations were concordant, in most instances differing by less than 0.2 per cent. The ratio of the hygroscopic coefficient to the found hygroscopic moisture (Table VII) shows an average of 2.71 and, with the exception of the first foot at Hastings and the fourth at Wauneta, lies between 2.38 and 2.96, a range of less than 25 per cent.

TABLE VII.—*Hygroscopic moisture in a series of air-dried loess soils and its relation to the hygroscopic coefficient in these soils*

HYGROSCOPIC MOISTURE

Depth.	Wauneta.	McCook.	Holdredge.	Hastings.	Lincoln.	Weeping Water.	Average.
Foot.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	3.1	3.5	3.8	3.0	4.2	4.1	3.6
2	3.4	4.0	4.7	4.2	5.5	4.9	4.4
3	3.4	3.7	4.7	4.6	5.4	5.0	4.4
4	3.3	3.4	4.3	4.3	5.0	4.9	4.2
5	3.2	3.2	4.0	4.1	4.9	4.8	4.0
6	2.8	3.2	3.8	4.2	4.8	4.7	3.9
Average	3.2	3.5	4.2	4.1	5.0	4.7	4.1

RATIO OF HYGROSCOPIC COEFFICIENT TO HYGROSCOPIC MOISTURE

1	2.93	2.86	2.66	3.20	2.86	2.95	2.91
2	2.82	2.72	2.38	2.76	2.62	2.80	2.68
3	2.85	2.89	2.40	2.70	2.52	2.78	2.69
4	3.00	2.85	2.38	2.58	2.60	2.65	2.68
5	2.81	2.93	2.40	2.61	2.61	2.62	2.66
6	2.96	2.84	2.47	2.60	2.64	2.66	2.69
Average	2.91	2.80	2.45	2.70	2.62	2.76	2.71

CALCULATED HYGROSCOPIC COEFFICIENT *a*

1	8.4	9.5	10.3	8.1	11.4	11.1	9.8
2	9.2	10.8	12.7	11.4	14.9	13.3	12.0
3	9.2	10.0	12.7	12.5	14.6	13.6	12.1
4	8.9	9.2	11.7	11.7	13.6	13.3	11.4
5	8.7	8.7	10.8	11.1	13.3	13.0	10.9
6	7.3	8.7	10.3	11.4	13.0	12.7	10.6
Average	8.7	9.5	11.4	11.1	13.6	12.7	11.2

DEPARTURE OF CALCULATED FROM DETERMINED HYGROSCOPIC COEFFICIENT

1	−0.7	−0.2	0.2	−1.5	−0.6	−1.0	−0.7
2	− .4	− .1	1.5	− .2	.5	− .4	.1
3	− .5	− .7	1.4	.1	1.0	.4	.2
4	−1.0	− .5	1.5	.6	.6	− .3	.3
5	− .3	− .4	1.2	.4	.5	− .4	.3
6	−1.0	− .4	.9	.7	.4	− .2	.1
Average	− .6	− .4	1.1	.1	.5	− .3	.1

[a] Using ratio found with control soils H and S.

The control soils H and S, exposed in the second set, contained 2.3 and 7.4 per cent of hygroscopic moisture, respectively, thus giving ratios of 2.44 and 2.98, respectively, with an average of 2.71. The hygroscopic coefficients calculated from the hygroscopic moisture, using this average ratio, and the departures of these from the directly determined values are reported in Table VII. In general, the departure is slight and on the average is negligible. However, it should be pointed out that the latter circumstance is due to the average of the ratios for the two control soils being the same as that for those of the 36 samples under consideration. If we had used only H as a control, the calculated values would have been one-tenth higher, while if S alone had been employed, they would have been one-tenth lower. In either of these two cases, however, the calculated values would have been much nearer the directly determined hygroscopic coefficients than would the values computed from the moisture equivalents by the Briggs-Shantz formula (3, p. 839).

We similarly exposed several other series of soils of which the hygroscopic coefficients had already been determined. The concordance of the calculated with the found values was much alike in all. The first of these series, which was strictly typical, is reported in Table VIII. It consisted of 24 samples, part surface soils and part subsoils, but all derived from residual material in western Nebraska. The soils were exposed on metal trays on the shelves of an inclosed basement room for two weeks, April 29 to May 13. The maximum temperature recorded in the room during this period was 22° C., and the minimum 18°; observations in this room, extending over three years, had shown that there was but rarely a daily range exceeding one degree. In the table the soils are arranged in order of texture. The ratio for the two control soils exposed in triplicate was 2.9. The data on the determined hygroscopic coefficients are the means of duplicate determinations. The calculated values in nearly all cases agree satisfactorily with those directly determined. The greatest divergences are shown by soils 13 and 23, the calculated hygroscopic coefficient being one-sixth too low for the former and one-seventh too high for the latter.

Finally we exposed on paper pie plates 145 soils of which the hygroscopic coefficients had not been determined. Each soil was exposed in duplicate and there were also 15 plates of each of two control soils, La and S. In the case of both of the control soils triplicate samples were exposed in different parts of the room in order to determine whether the position in the small room exerted a marked influence upon the amount of hygroscopic moisture absorbed. During the eight days of exposure, June 5 to 13, the temperature ranged from 18° to 23° C.

The position in the room was found to have a slight but appreciable influence upon the amount of moisture absorbed, the extremes being shown by two shelves, on one of which the samples of S and La were found to have 9.3 and 3.8 per cent, respectively, and on the other 8.7

and 3.3. The averages for the 15 samples of each were 8.9 for S and 3.5 for La. The ratio was accordingly 2.47 for S and 2.74 for La, the hygroscopic coefficients being 22.0 and 9.6 per cent, respectively.

TABLE VIII.—*Comparison of the determined hygroscopic coefficients with those computed from the hygroscopic moisture in a series of residual soils from southwestern Nebraska*

Soil.	Hygroscopic moisture.	Hygroscopic coefficient.			Ratio of hygroscopic coefficient to hygroscopic moisture.
		Determined.	Computed.	Departure.	
	Per cent.				
H (control)	1.9	5.6	.....	.....	2.9
S (control)	3.5	10.2	.....	.....	2.9
1	.3	.8	0.9	0.1	2.7
2	.3	.8	.9	.1	2.7
3	.3	.8	.9	.1	2.7
4	.3	.9	.9	.0	3.0
5	.4	1.1	1.2	.1	2.8
6	.4	1.1	1.2	.1	2.8
7	.4	1.4	1.2	−.2	3.5
8	.5	1.4	1.4	.0	2.8
9	.7	2.2	2.0	−.2	3.1
10	.8	2.2	2.3	.1	2.8
11	1.7	4.4	4.9	.5	2.6
12	1.3	4.5	3.8	−.7	3.5
13	1.8	5.4	5.2	−.2	3.0
14	1.7	5.9	4.9	−1.0	3.5
15	2.4	6.6	7.0	.4	2.7
16	2.5	8.0	7.2	−.8	3.2
17	2.9	8.3	8.4	.1	2.8
18	2.7	8.4	7.8	−.6	3.1
19	3.5	9.7	10.1	.4	2.8
20	3.6	9.8	10.4	.6	2.7
21	3.6	10.7	10.4	−.3	3.0
22	3.6	10.8	10.4	−.4	3.0
23	5.7	14.4	16.5	2.1	2.6
24	5.2	14.9	15.1	.2	2.9

At this point the removal of the junior author to California interrupted the work, but during the following year Mr. A. Skudrna made single determinations of the hygroscopic coefficients in the usual manner, using also the same control samples. In Table IX are shown the ratios of typical sets for various fields, the others being similar. It will be seen that the ratio is not affected by the presence of organic matter, as in the surface 6 inches it is similar to that in the subsoil.

This set serves well to illustrate the advantage of the indirect method of determination. During the early part of May the samples had been collected from 23 fields in western Nebraska for the study of field moisture conditions, which happened to be of unusual interest at that time, a wet winter and early spring having succeeded an exceptionally dry summer and autumn. The moisture samples had been weighed into light cotton sacks and dried at 110° C. to constant weight, and then left exposed to the air for a week or two before being placed on the plates in the so-called "constant temperature room." By the middle of June, as it later proved, reliable data on the unusual field moisture conditions

were at hand. The ratio varied in the case of the individual soil samples from 2.0 to 2.7, and the average ratio for the different fields only from 2.1 to 2.6. While the ratio tended to be higher in the coarse-textured soils there were many exceptions to this generalization.

TABLE IX.—*Ratio of hygroscopic coefficient to hygroscopic water in air-dried soils from typical fields in western Nebraska, May, 1912*

Depth.	Prairies.			Corn stubble.			Winter wheat.		Average of all.
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	
Foot.									
0–½	2.7	2.4	2.5	2.3	2.5	2.2	2.2	2.1	2.4
½–1	2.7	2.4	2.6	2.5	2.6	2.2	2.2	2.1	2.4
2	2.3	2.4	2.7	2.1	2.4	2.4	2.0	2.0	2.4
3	2.7	2.3	2.6	2.1	2.4	2.2	2.2	2.2	2.3
4	2.5	2.2	2.5	2.2	2.1	2.4	2.2	2.1	2.3
5	2.6	2.2	2.6	.....	2.0	2.3	2.1	2.3	2.3
6	2.6	2.1	2.3	2.3	2.5	2.6	2.1	2.0	2.3
Average	2.6	2.3	2.5	2.3	2.4	2.3	2.1	2.1	2.3

Table X and figure 1 show the concordance of the data on free water, using in the one case the computed and in the other the directly determined hygroscopic coefficients. Whichever set, B or C, is used, the same general moisture relations are shown, and for the purposes of the

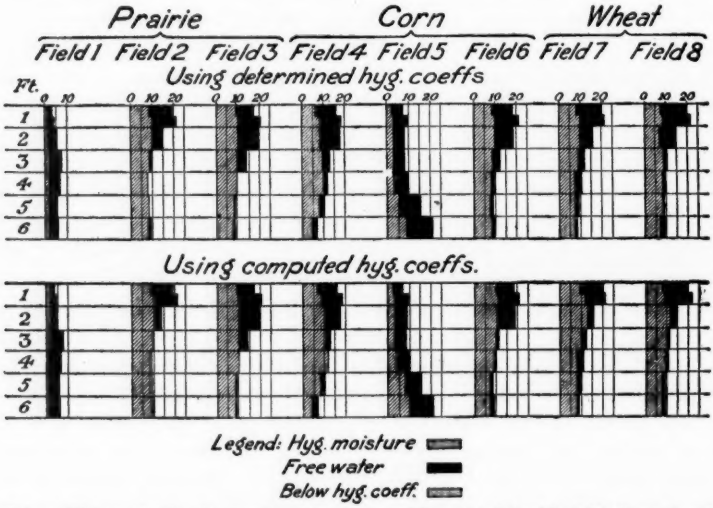

FIG. 1.—Diagram showing the amounts of free water at different levels in eight fields, illustrating the concordance of the values obtained for the hygroscopic coefficient by calculation from the hygroscopic moisture with those directly determined.

field moisture study they are almost equally satisfactory, but the data in C were all at hand a month after the field work had been completed, while those in D were not obtainable within half a year without dealing with this particular series out of its regular order.

TABLE X.—*Moisture conditions in typical fields of western Nebraska in May, 1912, showing the applicability of the data obtained by computing the hygroscopic coefficient from the hygroscopic water in the air-dried soil*

A.—TOTAL WATER IN SOIL IN FIELD

Depth.	Prairies.			Corn stubble.			Winter wheat.	
	I	II	III	IV	V	VI	VII	VIII
Foot.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
0–½	3.6	19.4	17.1	16.3	7.3	18.9	20.4	20.1
½–1	4.5	21.6	20.2	18.7	10.0	21.6	21.5	22.0
2	5.4	14.3	19.9	17.8	8.7	19.3	16.0	15.1
3	7.9	9.4	14.3	13.1	8.5	13.8	12.3	10.5
4	6.9	8.0	9.6	12.0	10.0	9.8	10.7	9.6
5	5.9	8.1	9.1	10.5	15.6	9.2	9.4	9.4
6	6.1	8.8	9.1	6.9	21.3	9.4	8.8	9.6
Average [a]	6.0	11.5	13.4	13.0	12.1	13.6	13.0	12.5

B.—FREE WATER (USING DETERMINED HYGROSCOPIC COEFFICIENTS)

0–½	2.0	10.8	8.2	10.4	5.3	10.4	12.2	12.8
½–1	2.9	11.0	10.7	10.5	7.1	11.5	11.2	13.4
2	3.8	4.0	9.5	9.5	6.1	9.1	6.2	7.3
3	6.0	1.1	4.3	3.7	5.9	5.3	3.9	1.1
4	5.4	.5	.0	2.0	7.0	1.7	2.9	.9
5	4.6	.3	.7	2.7	10.0	1.5	1.9	.8
6	4.8	1.2	1.5	2.4	12.4	.9	1.4	2.1
Average	4.2	3.0	4.0	5.1	7.9	4.9	4.7	4.2

C.—FREE WATER (USING COMPUTED HYGROSCOPIC COEFFICIENTS)

0–½	2.1	10.5	7.9	9.7	5.3	9.0	10.7	12.6
½–1	3.0	10.2	10.7	10.3	7.2	10.1	9.8	12.8
2	3.6	3.1	10.2	7.8	5.9	8.6	3.1	3.6
3	6.1	.0	4.6	1.9	5.7	4.1	2.4	−.4
4	5.4	−.7	−.1	.3	6.4	1.1	2.7	−.8
5	4.6	−.8	.7	.....	8.3	1.3	1.4	1.6
6	4.8	−.3	.7	2.6	12.1	1.5	1.0	1.8
Average	4.2	1.9	4.2	[b] 4.2	7.4	4.4	3.5	3.1

[a] In estimating both the average hygroscopic coefficient and the average moisture content of the 6 feet of soil we have employed the mean for the first foot instead of averaging the seven data in each column.
[b] In estimating the average the missing datum is replaced by that from the preceding part of the table.

It should be pointed out that in the case of all the soils with which we have employed the simpler method so satisfactorily the samples either had been dried at 110° C. or for many months had been exposed to the dry air of the storeroom and so had attained an air-dried condition. As it would in many instances be more convenient if the moist samples could be exposed on paper trays or plates and left until they came into equilibrium with the atmosphere, we exposed for varying periods—2 to 21 days—10 to 15 gm. samples of the control soils, H, La, and S, all containing the maximum hygroscopic moisture, together

with samples of the same soils dried at 100° C. and still others that were in an air-dried condition. At the end of from 3 to 7 days those of the second and third sets were alike in moisture content, while those of the first were distinctly moister. A difference was frequently shown even after an exposure of 21 days.

Using 5-, 10-, 15-, and 20-gm. samples of the same three control soils we compared paper with aluminum trays. Both gave the same results with H and La, but in some cases S, which had a coefficient of 22.0, gave a somewhat lower result on the paper trays, 7.7 as compared with 8.0, as though, following an increase in the relative humidity of the air, the material of the trays, being in itself hygroscopic, had competed with the contained soil for moisture from the atmosphere.

From the above statements it would appear that once having accurately determined the hygroscopic coefficient of suitable control soils it would only be necessary to expose for a few weeks on trays in a closed room thin layers of the air-dried or oven-dried soils under investigation, together with a sufficient number of trays containing the control soils. After sufficient exposure the mere determination of the hygroscopic moisture in all would permit of the calculation of the hygroscopic coefficients. Thus, the hundreds or thousands of samples which might be collected during the summer in connection with a soil survey might be placed in trays on the shelves as they reached the laboratory, the drying being left until winter. There could then be obtained that single-valued factor expressing texture which appears to us the most desirable of all those so far proposed (1, p. 214).

In connection with the method there remains to be determined, among other things, the minimum time of exposure necessary, the most suitable material for trays, the desirability of providing for the agitation of the air in the exposure room and maintaining the humidity of the air in the room between definite limits.

This indirect method of estimating the hygroscopic coefficient appears to give more reliable results than those to be obtained by the use of a single formula applied to either the mechanical composition (2, p. 411) or the moisture equivalent (3, p. 842), while at the same time requiring only the simplest equipment, as well as a minimum of skill on the part of the operator, and being economical of time.

SUMMARY

The estimation of the hygroscopic coefficient from the maximum water capacity, while with many soils giving values in full accord with those directly determined, with so many soils gives such erroneous results that it is to be regarded as too unreliable for use in connection with either studies of available soil moisture or for soil-survey purposes.

From the studies reported it appears that the hygroscopic coefficient may be calculated from the hygroscopic moisture found in a soil which

has been allowed to come into equilibrium with an only partially saturated atmosphere and that this method will require only simple equipment, a minimum of skill on the part of the operator, and be so economical of time as to recommend it wherever a very large number of samples have to be dealt with.

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CORRELATION BETWEEN THE SIZE OF CANNON BONE IN THE OFFSPRING AND THE AGE OF THE PARENTS [1]

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Jensen (3)[3] and the writer (12, 13) have both found that in the Jutland and Gudbrandsdal horses the young and relatively young animals have given the best offspring and that old animals have very seldom produced high-class stallions. Both of these breeds are selected for heavy bones. On the other hand, in the English thoroughbred, which is selected for speed, old horses produce high-class animals for that purpose. It is, then, naturally suggested that an investigation be made as to whether young parents are producing heavier cannon bones than old parents. Von Oettingen (7) noticed this in numerous cases and stated that the offspring of the halfbred stallions Halm, Harnish, and Optimus (in Gudwallen and Trakehnen, Germany), with relatively heavy bones, tended to become slender in the cannon bones when the stallions became old. Jensen made a similar statement in a letter to the author about the offspring of the famous Jutland stallion Aldrup Munkedal. The writer has also had the same experience with Gudbrandsdal stallions. In Percheron horses bred in France, where young stallions and mares are much used for breeding purposes, it is recognized that the breed shows a big increase in cannon-bone size. This can not be substantiated by measurement, but it seems to be a fact. Of statements concerning other mammals that show a similar tendency, it is worth while to cite Stonehenge's (11) observation concerning dogs: "When, however, the produce is desired to be very small, the older both animals are the more likely this result is."

When these views are considered, although they are not supported by any scientific measurements, there seems to be good reason for undertaking an investigation of the correlation between the age of the parents and the measurements of the cannon bone of the offspring. Fortunately the Gudbrandsdal stud book[4] contains material that is suitable for such an investigation. The writer selected as material for the investigation all mares measured in the "South of Norway" district

[1] Contribution from the Laboratory of Genetics, Agricultural Experiment Station of the University of Illinois.

[2] The author wishes to express his thanks to Prof. J. A. Detlefsen and Prof. H. L. Rietz, of the Illinois Station, for many suggestions and criticisms in connection with this investigation.

[3] Reference is made by number to "Literature cited," p. 370–371.

[4] Stambog over Heste av gudbranddalsk race. Bd. 3, 1906; Bd. 5, 1909; Bd. 6, 1913. Kristiania.

(Söndenfjeldske). These mares are all measured in the same way, and the measurements are registered in the stud book. The measurement is taken near the middle of the cannon bone, at its narrowest point. In the data the writer found five mares whose dams were 1 year old at the time of service. Both because this number is too small to give average values whose significance can be estimated, and because of the abnormal character of these extremely young dams, they have been excluded in the general treatment of the problem. Two other mares are excluded, one for the reason that the writer knows that her cannon bone is abnormally thickened, and the other because the measurement of the side breadth is abnormally small compared with the circumference.

Along with age, there are other causes that have an influence on the size of the cannon bone of the offspring. Heredity is the first of these causes to be considered, because it is probably of great importance in this particular investigation, since the modern Gudbrandsdal horses include blood lines that represent a cross between the original horse type of eastern Norway (the most northern branch of the occidental horse) and different light-horse types. In the seventeenth and eighteenth centuries there were imported into Norway stallions of the Fredricsborgian horse or a closely related type. The Fredricsborgian horse was a light-horse type that descended from crosses of Seeland country horses, Spanish, and oriental horses. In the nineteenth century there was imported into Norway an English thoroughbred stallion, Odin. This stallion became by chance the founder of one of the most important stallion lines of the Gudbrandsdal breed. In the nineteenth century the blood of the other Norwegian breed, the Fjord horse, was mixed with the Gudbrandsdal horse by the use of several mares, and thus became an influence on the latter breed (12, 13). If cannon-bone size is inherited, it is perfectly clear that the Gudbrandsdal horse is not a purebred in a genetic sense, since extreme heterozygosis must result from the numerous infusions of blood from such diverse sources.

One should consider the influence of nourishment on the size of the cannon bone, but the number of individuals in this investigation is so large and the conditions of nourishment are such that the effects of different nourishments would probably eliminate each other, or at least would be insignificant. Although nutrition undoubtedly has a pronounced effect upon size and growth, the writer has assumed that under good conditions the adult size of the cannon bone represents in a fair way the inherent possibilities of an animal. Such has been the usual assumption in genetic investigations of size characters.

The first task was to calculate the correlation between the age of the sires and the size of the cannon bone of female offspring. Table I gives the number and kinds of mares sired by stallions of different ages. Measurements under 18 cm. and over 21 cm. are arranged in the subclass headed 18 and 21, respectively. The averages of arrays

are calculated from the original figures before they were grouped in a correlation table. The age of the stallions is arranged in classes with 3-year intervals in each class—that is, class 1 is composed of stallions 2 to 4 years old; class 2 is composed of stallions 5 to 7 years old, etc. In this notation 2 to 4 means under 5, 5 to 7 means under 8, and so on. The correlation coefficient is -0.061 ± 0.012. Although the coefficient of correlation is five times as large as the probable error, the negative correlation is so small that it indicates only a very slight tendency for older sires to beget daughters with smaller cannon bones. The average size of cannon bone decreases slightly as the age of the sires increases. The difference between size of cannon bone for the mares whose sires are 5 to 7 years old and the mares whose sires are 17 years of age or older is 0.111 ± 0.036.

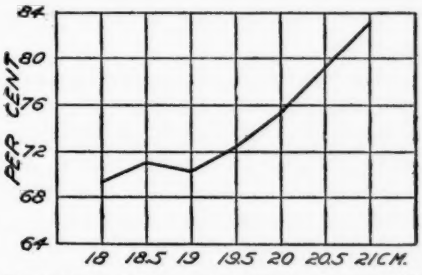

FIG. 1.—Curve showing the percentages of mares with various-sized cannon bones, sired by stallions under 11 years old.

TABLE I.—*Correlation between the age of the sires and the measurement of the cannon bones of the female offspring*

Age of stallion.	Number of female offspring having a cannon bone of a given size (cm.).								Average size of cannon bone.
	18	18.5	19	19.5	20	20.5	21	Total.	
Years.									*Cm.*
2 to 4.....	26	58	143	96	72	14	6	415	19.273±0.021
5 to 7.....	73	137	387	182	178	44	22	1,023	19.272±0.014
8 to 10.....	60	99	252	107	135	22	16	691	19.244±0.017
11 to 13.....	33	61	166	75	73	11	7	426	10.219±0.021
14 to 16.....	24	37	102	47	37	7	2	256	19.175±0.026
17 and older....	10	23	58	26	20	3	0	140	19.161±0.033
Total.....	226	415	1,108	533	515	101	53	2,951	

$r = -0.061 \pm 0.012$

Figure 1 shows the percentages of all mares of various size classes sired by stallions 10 years and younger. To be sure, more mares of all classes were sired by stallions under 11 years old, but it is interesting to note that gradually increasing percentages of the larger mares were sired by these younger stallions. To state this differently, mares whose cannon bone measures more than 19.5 cm. are more likely to come from sires under 11 years of age than are the mares whose cannon bone measures under 19.5 cm. There is a perceptible rise in the curve beginning at the 19.5 cm. Figure 1 was plotted from Table I by taking the ratio of the

number of mares in any given class whose sires were under 11 years to the total number of mares in that class. It would seem from the curve that a decided negative correlation existed, but one must remember that rapid rise in the right-hand part of the curve (20 cm. and above) is based upon 669 cases, whereas the left-hand portion is based upon 2,281 cases.

To get sufficiently large numbers and as homogeneous material as possible, the author has taken out for investigation daughters of five Government and five association stallions, each of which has more than 25 registered daughters, of which at least 10 are sired before or after the stallion was 10 years old (Table II). The following observations may be made from the table in regard to the average size of cannon bone for the daughters of these stallions.

TABLE II.—*Average size (in centimeters) of cannon bone in the daughters of 10 selected males, grouped according to the age of the males*

Name of sire.	Age of sire.	Total number of daughters.	Number of daughters having a cannon bone of a given size (cm.).							Average.	Difference.
			18	18.5	19	19.5	20	20.5	21		
Digre 222....	10 years and younger....	13	0	1	7	2	2	1	0	19.33 ±0.099	0.24±0.12
	Older than 10 years.....	25	3	3	13	2	3	0	1	19.09 ±0.074	
Bamsen 254..	10 years and younger....	13	0	0	7	0	6	0	0	19.52 ±0.085	0.41±0.12
	Older than 10 years.....	22	2	3	10	4	2	1	0	19.11 ±0.082	
Dölen 260....	10 years and younger....	11	1	2	1	2	5	0	0	19.39 ±0.14	0.39±0.16
	Older than 10 years.....	18	2	5	5	4	2	0	0	19.00 ±0.092	
Sverre 270...	10 years and younger....	10	0	0	7	0	3	0	0	19.30 ±0.096	0.06±0.11
	Older than 10 years.....	36	1	7	15	5	6	2	0	19.24 ±0.058	
Sindre 297...	10 years and younger....	36	3	2	13	8	9	1	0	19.35 ±0.058	0.11±0.10
	Older than 10 years.....	31	4	4	8	8	5	1	1	19.24 ±0.07	
Bjarne 301...	10 years and younger....	16	0	3	4	1	6	1	1	19.55 ±0.13	0.52±0.15
	Older than 10 years.....	29	2	6	14	4	3	0	0	19.03 ±0.068	
Galde 372....	10 years and younger....	60	3	4	19	9	20	3	2	19.49 ±0.061	−0.03±0.083
	Older than 10 years.....	37	1	1	11	10	14	0	0	19.52 ±0.057	
Kongen 376..	10 years and younger....	25	5	2	8	3	5	2	0	19.17 ±0.11	−0.21±0.16
	Older than 10 years.....	13	0	0	8	2	2	0	1	19.38 ±0.11	
Gimle 425....	10 years and younger....	69	2	5	20	19	17	3	3	19.51 ±0.051	0.90±0.09
	Older than 10 years.....	38	2	5	6	12	10	2	1	19.51 ±0.074	
Dalegud-brand 466..	10 years and younger....	47	3	3	14	11	5	5	6	19.57 ±0.086	0.19±0.11
	Older than 10 years.....	13	0	0	6	5	2	0	0	19.38 ±0.073	
Total..	10 years and younger....	300	17	22	100	55	78	16	12	19.448±0.026	0.216±0.037
	Older than 10 years.....	262		34	96	56	49	6	4	19.232±0.027	

Either the average for daughters sired when the stallion was 10 years old or younger, or the average when the stallion was older than 10 years, or the average in both these cases, is larger than the average for the breed.

Table II shows that for offspring of 7 of the 10 stallions the average size of the cannon bone is larger when the sire was 10 years old or younger at the time of service. The difference is not so large that it is significant in every case considered singly. The offspring of two, Galde and Gimle, of the remaining three sires show practically the same average for the two classes. The third stallion, Kongen, has a larger average for the daughters that he sired when he was older than 10 years. With such small numbers as 25 and 13 this deviation of this result from

our other results may be a chance fluctuation. In fact, the apparent lack of harmony of this case with the others is largely due to the size of the cannon bone of one mare—21 cm. This mare was sired when the stallion, Kongen, was 12 years old. The mother was 6 years old. With all 10 stallions it is remarkable how few there are of the daughters with a circumference of 20.5 and 21 cm. in that class which was sired when the stallions were older than 10 years. Taking the two classes as a whole, the writer finds for all daughters sired when the stallions were 10 years old and younger at time of service that the average cannon bone is 19.448 ± 0.026 and for the other class the average is 19.232 ± 0.027. The difference, 0.216 ± 0.037, is significant, for the difference is nearly 6 times the probable error. Figure 2 shows the percentage of the daughters of the 10 stallions that correspond to different sizes of cannon bone when the stallions were 10 years and younger at the time of service. Just as in the case of figure 1, there is a perceptible rise, the curve beginning at 19.5 cm. In other words, gradually increasing percentages of the larger mares (those over 19.5 cm.) were sired by these stallions when 10 years old or younger.

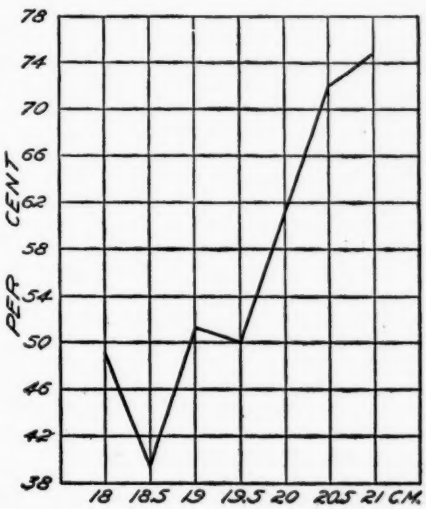

FIG. 2.—The percentages of mares with various-sized cannon bones, sired by 10 selected stallions when these were under 11 years old.

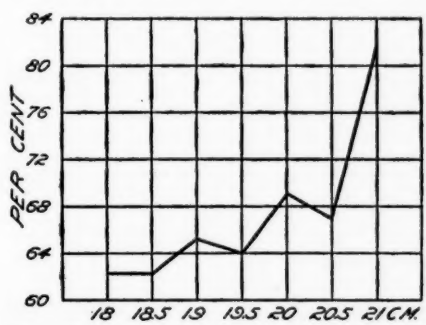

FIG. 3.—The percentages of mares of various-sized cannon bones bred from dams under 11 years old.

The correlation between the age of the dams and the size of the cannon bone of their female offspring was calculated to ascertain whether a similar relationship held as in the case of the sires in Table I. Curiously enough, the coefficient (-0.062 ± 0.017) is practically the same as that given in Table I. The total number of variates is not as large as that given in Table I, for the age of the dam is not as frequently registered

as that of the sire. Table III gives the number of mares bred by dams in the different age classes. The averages show that the young dams 2 to 4 years old have given offspring with the heaviest cannon bone. The difference between these and the class that has the lowest average is 0.159±0.039. The average for the class with dams 14 to 16 years old is 19.341±0.035. This average is practically the same as the average for the mares in the classes 5 to 7 and 8 to 10 year old class. This large average is due to the 41 mares with a circumference of 20 cm. Of these, 20 are sired by stallions 2 to 7 years old. Figure 3 shows the percentages of mares bred from dams 10 years old and younger. In this case also the rise begins in the neighborhood of 19.5 cm., and agrees with figures 1 and 2 in this respect.

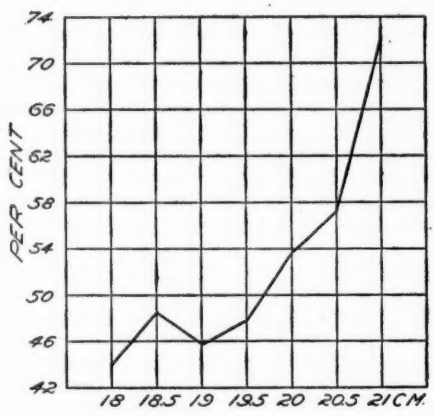

FIG. 4.—The percentages of mares of various-sized cannon bones bred from both parents under 11 years old.

TABLE III.—*Correlation between the age of the dams and the size of the cannon bone of the offspring*

Age of dam.	Number of offspring having a cannon bone of a given size (cm.).								Average size of cannon bone.
	18	18.5	19	19.5	20	20.5	21	Total.	
Years.									*Cm.*
2 to 4	13	34	80	65	60	15	9	276	19.404±0.028
5 to 7	21	48	155	87	87	17	12	427	19.344±0.023
8 to 10	22	32	177	70	66	18	7	332	19.340±0.025
11 to 13	14	37	103	56	32	14	4	260	19.245±0.027
14 to 16	13	16	57	33	41	9	2	171	19.341±0.035
17 and older	7	16	34	36	22	2	0	117	19.271±0.037
Total	90	183	546	347	308	75	34	1,583	

$r = -0.062 \pm 0.017$

In order to get a general view of the relation of the age of both parents to the size of the cannon bone of their offspring, the writer has computed in Table IV the average size of the cannon bone of the female offspring grouped according to whether both, either one, or neither of the parents was under 11 years of age. The differences between the averages in these groups are not striking, except when both parents are under 11 years old.

Figure 4 shows a rise beginning at 19.5 cm., which indicates that matings of parents both under 11 years old have given gradually increasing percentages of the larger size classes.

TABLE IV.—*Average size of the cannon bone in the females in relation to the age of both parents*

Age of parents.	Number of females having a cannon bone of a given size (cm.).								Average size of cannon bone.
	18	18.5	19	19.5	20	20.5	21	Total.	
									Cm.
Both parents 10 years old and younger	40	89	251	166	165	43	25	779	19.386±0.020
Sire 10 years old and younger, the dams older than 10 years	26	53	144	98	66	20	5	412	19.277±0.021
Sire older than 10 years, the dam 10 years old and younger	16	25	101	56	48	7	3	256	19.275±0.026
Both parents older than 10 years	8	16	50	27	29	5	1	136	19.291±0.036
Total	90	183	546	347	308	75	34	1,583	

TABLE V.—*Averages of the deviations of the daughters from their dams, grouped according to the age of both parents*

Age of parents.	Number of daughters having a given deviation in the size of the cannon bone (cm.).												Average deviation.
	−2.5	−2	−1.5	−1	−0.5	0	0.5	1	1.5	2	2.5	3	3.5	Total.	
															Cm.
Both parents 10 years old and younger	0	4	17	66	104.5	133	98.5	97.5	35	10.5	1	0	1	568	0.131±0.024
The sire 10 years old and younger. The dams older than 10 years	0.5	5.5	8.5	24.5	34	60.5	39	29	12.5	2.5	0.5	1	0	218	0.046±0.040
The sire older than 10 years. The dam 10 years old and younger	1	3	7	18.5	38	50	38	24	5	1.5	0	0	0	186	−0.016±0.039
Both parents older than 10 years	0	2	1.5	4	12.5	17	10.5	7	5.5	0	0	0	0	60	0.067±0.072

To show how the measurements of the cannon bones of the offspring deviate from those of the parents the writer has tabulated (Table V) the deviations of the daughters from the dams—that is, when the measurement of the cannon bone of the dam is 20 cm. and the cannon bone of the daughter is 19 cm., the daughter is entered in Table V under −1. In this table the mares that have both parents 10 years old and younger give an average deviation of 0.131 ±0.024 above the dam. This is 5½ times as large as the probable error. For the mares that have the sire 10 years old and younger, the dam being older than 10 years, and the mares with both parents older than 10 years, the difference is practically the same as the probable error. For the mares whose sires are older than 10 years and the dam younger, the difference is slightly negative

It is noteworthy that the daughters deviate from the dams by a significant amount only when both parents are 10 years old and younger, and in this case the daughters are larger than the dams in cannon-bone circumference. Figure 5 shows the percentages of mares in the various classes with both parents 10 years of age and younger. The curve was constructed from Table V. The offspring of parents under 11 years of age constitute about 55 per cent of the total number of individuals entered in the table, but the curve shows that the percentage of the daughters which average higher than their dams is greater than 55 per cent when both parents are under 11 years of age.

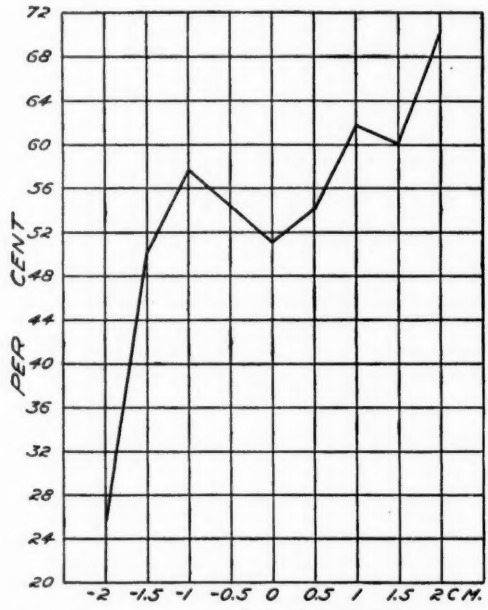

FIG. 5.—The percentages of mares in various classes deviating from their dams when both parents were under 11 years old.

It takes large numbers to establish the significance of the differences with which we are concerned in this paper, and it is to be hoped that further data will be obtained in order to test this matter for other heavy breeds. However, the present study points to the following conclusions:

(1) The age of the parent has an influence on the circumference of the cannon bone of the offspring.

(2) Immature parents 2 to 4 years old give offspring with the same measurement of the cannon bone as parents as old as 5 to 7 years.

(3) Parents older than 10 years considered as a class give offspring with lighter cannon bones than parents 10 years old and younger. In the breed examined there was found a larger percentage of individuals over average size whose parents were 10 years old or younger. On the other hand, the average individuals and those smaller have parents which are just as frequently under 10 years old as they are over. In other words, the lighter classes of cannon bone come as frequently from young as from old parents, but the heavier classes seem to come more frequently from younger parents.

(4) There seems to be some basis for the current opinion among breeders of Gudbrandsdal and other heavy breeds that young parents give better offspring than older parents.

It is extremely difficult to connect the data obtained with current genetic hypotheses and conceptions. The history of the Gudbrandsdal heavy horses leads one to expect heterozygosis. That the heavy registered mares and stallions should give a range of types is not surprising in itself, for such a recent breed can hardly be expected to breed true. However, in genetic investigations on size, segregation is supposed to be independent of age, and an increased proportion of large-sized offspring from the younger parents is hardly expected. It will naturally occur to the critical that circumstances entirely independent of heredity underlie these peculiar frequencies of the size classes. For example, one wonders whether more large offspring from young stallions and young mares are not registered in order to establish their reputation; or may not young stallions be mated to high-grade mares in order to make a better showing as sires, whereas this selection in mating would not be as rigorous after the sire had proven his worth? Many years of familiarity with this breed and with the methods of registration lead the writer to attach but little value to these considerations. The best mares and the best sires are those which are kept the longest for breeding purposes. The fact that measurements must accompany registration has prompted careful selection at all ages.

Available measurements or investigations that throw light on the inheritance of size in horses are scarce. It is not known whether cannon-bone size in horses is due to multiple factors such as are postulated in recent investigations on size in poultry by Punnett and Bailey (10), in rabbits by MacDowell (5), in ducks by Phillips (8, 9), in guinea pigs by Detlefsen (1), in corn by Emerson and East (2), and the like. The investigation of Landman (4) may throw some light on the inheritance of cannon-bone size in horses. East Prussian country mares, with relatively small cannon bones, were graded up by crossing them with Belgian stallions. Although the total numbers recorded are smaller than is desired as a basis for conclusions, they indicate the gradual rise in the hybrid animals approaching the average for Belgian mares (Table VI).

TABLE VI.—*Sizes of the cannon bone in the East Prussian country mares, Belgian mares, and three hybrid generations*

Animal.	Number of horses having a cannon bone of a given size (cm.).																	Average size of cannon bone.
	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22	22.5	23	23.5	24	24.5	25	
East Prussian country mares	3	...	6	10	14	7	6	...	...	...	...	...	...	...	...	...	...	*Cm.* 18.83
F_1 generation	...	...	1	2	6	6	10	4	8	7	...	...	1	...	...	...	...	20.17
F_2 back cross	...	...	...	...	...	1	2	6	6	12	6	1	2	...	1	...	...	21.38
F_3 back cross	...	...	...	...	...	...	...	...	3	1	1	3	1	...	1	...	...	22.10
Belgian mares	...	...	...	...	...	...	...	1	...	1	...	2	2	1	4	2	3	23.53

The measurements for the Belgian mares are those given by Von Nathusius (6). The inheritance is what is usually called blending, but it was shown by Detlefsen (1) and others that such back crosses with apparently blending inheritance are susceptible of a Mendelian interpretation, on the basis of multiple factors incompletely dominant. If this interpretation of Landman's data (4) is correct, then heavy-horse types may contain factors for lighter bone. The heavy but heterozygous Gudbrandsdal horses may well give light cannon bone, for their history shows the infusion of much light-horse blood. The writer hesitates to advance the tentative hypothesis that segregation of size factors in horses may be influenced by age, but some such hypothesis is necessary to account for the poor performance of older stallions when compared with young. Race-horse stallions have been known to give excellent results when very old, for they are not bred for the dominant heavy-bone characters. Draft horses of the Gudbrandsdal and other heavy-horse breeds have not given similar satisfactory results. The reason may lie in the possibility that older stallions and mares are responsible for more recessives, whereas the younger give more dominants. Any such hypothesis, however suggestive, must be recast in the light of future investigations.

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LASPEYRESIA MOLESTA, AN IMPORTANT NEW INSECT ENEMY OF THE PEACH

[PRELIMINARY PAPER]

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INTRODUCTION

Attention is called to the discovery in the District of Columbia and environs of an important insect enemy of the peach believed to be new to the United States and apparently not heretofore known to science. Observations on this species by the writers during the summer and fall of 1916 warrant the fear that another formidable insect enemy of the peach and other deciduous fruits has become established in America. The insect is a moth belonging to the tortricid genus Laspeyresia, which contains numerous species of prime importance as pests in different parts of the world. Thus, *Laspeyresia funebrana* Tr. is the common plum worm or plum maggot of Europe and is said to be plentiful in plum pies. *L. woeberiana* Schiff. in Europe bores the bark of peach, cherry, plum, and apple trees. *L. nebritana* is the common pea moth, and *L. schistaceana* Sn. is a sugar-cane pest of importance in Java. In America the most important species is *L. pomonella* L., as yet better known under the generic name "Carpocapsa." The lesser apple worm, *L. prunivora* Walsh; the pecan moth, *L. caryana* Fitch; and *L. pyricolana* Murtfeldt are other familiar examples of the genus.

DESCRIPTION OF THE MOTH

Mr. August Busck, of the Bureau of Entomology, has prepared the following description of the species with comment on its relationships and possible origin:

Laspeyresia molesta, n. sp.

Head dark, smoky fuscous; face a shade darker, nearly black; labial palpi a shade lighter fuscous; antennæ simple, rather stout, half as long as the forewings, dark fuscous with thin, indistinct, whitish annulations. Thorax blackish fuscous; patagia faintly irrorated with white, each scale being slightly white-tipped. Forewings normal in form; termen with slight sinuation below apex; dark fuscous, obscurely irrorated by white-tipped scales; costal edge blackish, strigulated with obscure, geminate, white dashes, four very faint pairs on basal half and three more distinct on outer half besides two single white dashes before apex; from the black costal intervals run very obscure, wavy, dark lines across the wing, all with a strong outwardly directed wave on the middle of the wing; on the middle of the dorsal edge the spaces between three of these lines are more strongly irrorated with white than is the rest of the wing, so as to constitute two faint and poorly defined, white dorsal streaks. All these markings are only discernible in perfect specimens and under a lens; ocellus strongly irrorated with white, edged by two broad, perpendicular, faint bluish metallic lines and containing several small,

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deep black, irregular dashes, of which the fourth from tornus is the longest and placed farther outward, so as to break the outer metallic edge of ocellus; the line of black dashes as well as the adjoining bluish metallic lines are continued faintly above the ocellus in a curve to the last geminate costal spots; there is an indistinct, black apical spot and two or three small black dots below it; a thin but distinct, deep black, terminal line before the cilia; cilia dark bronzy fuscous. Hind wings dark brown with costal edge broadly white; cilia whitish; underside of wings lighter fuscous with strong iridescent sheen; abdomen dark fuscous with silvery white underside; legs dark fuscous with inner sides silvery; tarsi blackish with narrow, yellowish white annulations.

Alar expanse: 10 to 15 mm.

United States National Museum type 20664.

The present species is very similar to the European *Laspeyresia funebrana*, which is an important enemy of stone fruits in Europe, and it was at first supposed that it might be this European species which had been accidentally introduced into America, but several minor discrepancies both in the ornamentation of the moth and in the biology of the larva made this determination uncertain, and specimens were therefore submitted to the European specialists, Messrs. Edward Meyrick and J. H. Durrant, both of whom pronounced the species distinct from *L. funebrana* and unknown to them.

There are several American species closely allied to *Laspeyresia molesta*, but it is unlikely that the species is a native of this country; it has more probably been accidentally introduced from Japan, where closely allied species also occur, though the present species has not hitherto been reported. The theory of the Japanese origin is strengthened by a single specimen of a species of Laspeyresia which was reared from a shipment of pears from Japan to Seattle, Wash. The writers are unable to differentiate this specimen from those reared from peach in the East, and believe it to be the identical species.

Among the American species *Laspeyresia molesta* may easily be confused with (*Epinotia*) *Laspeyresia pyricolana* Murtfeldt, which not only is very similar both in adult and larval stages but which has similar biological habits and has also been reared from peach in the vicinity of Washington, D. C.

Laspeyresia molesta is, however, a larger and less mottled species, without the dark-brown transverse facia on the forewing found in *L. pyricolana;* the hind wings are more rounded, especially in the males, and not so triangular as in *L. pyricolana*. The males of *L. pyricolana* can at once be distinguished by a large patch of black scales on the upper surface near the base of the hindwings and by a similar black patch on the underside of the forewings; no such ornamentation is found in the males of *L. molesta*.

FULL-GROWN LARVA

Thirteen to fifteen mm. long; whitish suffused with pink; tubercles minute, black. Head light brown with darker brown markings; hind margin, ocellar area, and the tips of the trophi black. Thoracic shield light yellow, edged with brown. Spiracles small, circular, dark brown. Anal plate blackish fuscous. Legs and prolegs normal.

DISTRIBUTION OF THE SPECIES

So far as known to the writers, the insect in the United States is still confined to the general region of the District of Columbia. It is very generally present on peach trees in yards and elsewhere in the city of Washington and adjacent towns in Virginia and Maryland within a radius of 15 or 18 miles. Examples of injury to the peach by what is believed to be this insect have, however, been seen in the environs of Baltimore. The insect is thought to have been present in the District of Columbia for four or five years, or perhaps somewhat longer. Specimens of injured twigs were received at the Bureau of Entomology in the fall of 1913, and the work attributed to an unknown lepidopterous larva, although they are now believed to have been injured by *Laspeyresia molesta*. A few examples of injured twigs were received or collected during 1914 and 1915, but it was not until the fall of 1915 that its injuries were at all common. The writers were, unfortunately, not successful in obtaining adults from the larvæ until the spring of 1916, and the single specimen then obtained did not prove sufficient for identification purposes. During the summer of 1916, however, an abundance of adults were reared and certain observations made concerning the biology and injuries of the insect.

CHARACTER OF INJURY AND HABITS

The larvæ have been found injuring twigs of the peach (*Amygdalus persica*), plum (*Prunus* spp.), and cherry (*Prunus* spp.) and the fruit of the peach. The scarcity of the plum and cherry during 1916 in the infested area prevented observations as to the extent to which these fruits are attacked. The plum and cherry, however, have not shown such general infestation as observed for the peach, and it would appear that this latter is the insect's preferred food plant. It should be stated, however, that flowering cherries growing here and there in parks in Washington, especially the extensive plantings of Japanese flowering cherries in Potomac Park, are very generally infested. The twig injury to the cherry and plum is essentially the same as for the peach, though it is less conspicuous, due to less gum exudation (Pl. 26, A, B).

TWIG INJURY

In one peach orchard under observation an examination in mid-September showed that from 80 to 90 per cent of the twigs had been injured, and an even higher percentage of twigs of adjacent peach nursery stock had been attacked. Its injuries to the twigs of bearing orchards, while important as interfering with normal growth, are of less significance than the injuries of the caterpillars to the fruit. Twig injury in nurseries, however, is of much more importance, as the destruction of the terminal growing shoots results in the pushing out of shoots from lateral buds, producing a much-branched and bushy plant unsuitable for nursery stock (Pl. 27). Twig injury to newly planted orchards and to replants

in bearing orchards is also quite important, and aside from the actual injury inflicted would interfere a good deal with the proper shaping of the tree.

Attack on the twigs begins in the spring when the shoots are from 6 to 8 inches long and continues until active growth of the trees ceases in the fall. Many twigs injured in the latter part of the season present the appearance shown in Plate 28, B. As the twig hardens, the larva may leave its burrow and feed more or less on the exterior of the twig, cutting holes and pits into the bark and causing a copious exudation of gum, rendering the injury quite conspicuous. The more typical injury to twigs in the fall, however, is that represented in Plate 28, A.

The larvæ prefer tender, actively growing shoots, and their injury to these (Pl. 29, A, B) is scarcely distinguishable from that of the common peach-twig borer, or peach moth (*Anarsia lineatella* Zell). The caterpillars pass from one shoot to another in their search for appropriate food, and several shoots may thus be injured by a larva in the course of its growth. A striking illustration of this preference for tender growth was noted in an orchard near by in Virginia. Here the orchard trees had practically ceased growth, and although a large percentage of the twigs showed injury a careful search of these resulted in finding no larvæ. In an adjoining block of seedling nursery trees still growing vigorously larvæ in all stages were found very abundant. Injury to the shoots is apparently continuous during the active period of growth of the trees, even in the presence of fruit. The writers' observations are not conclusive as to whether the fruit is preferred to the twigs.

INJURY TO FRUITS

The fruit may be attacked while quite green, the infestation increasing as it approaches maturity. Larvæ of all sizes have been found abundantly in peaches during the ripening stage from midsummer on. Midseason and early fall varieties have been noted as being worse infested, owing probably to the concentration of larvæ on the fruit by reason of the cessation of active growth of the twigs. Thus, in the case of some Salway and Smock trees and certain varieties of clingstone peaches, of similar season, practically all the fruit on the trees was infested with from one to three or four larvæ.

In attacking the fruit the young caterpillars rather generally eat through the skin at or near the point of attachment of the fruit stem, the place being indicated by more or less frass adhering to the surface of the fruit (Pl. 30, B). Entrance is also made at other places, especially where the fruit has been punctured by the curculio or abrased by limbs or branches or other causes, as by hail. If the fruit is ripe, or nearly so, the entrance point of the larva may soon be invaded by the brownrot fungus, the larva continuing its development, in frequent instances, in the fungus-invaded and decaying flesh of the peach. Owing to the com-

bined effect of the caterpillar and brownrot fungus, a good deal of fruit may fall to the ground, though the majority of the fruit infested by the caterpillars will remain hanging on the trees, especially if the fruit was invaded when nearly mature. If the peach be entered at the stem end, the larva as it grows makes its way to the pit, where it feeds on the flesh, which soon becomes much discolored and more or less slimy (Pl. 31). Larvæ entering at the side of the fruit are more likely to eat out pockets or cavities in the flesh, as shown in Plate 30, A. The inconspicuous entrance holes of the young larvæ, especially at the stem end, often render it difficult to detect wormy fruit by exterior examination. In numerous cases apparently sound fruit when cut open has been found infested with one or more larvæ.

PUPATION AND HIBERNATION

The caterpillar when full grown seeks some protected place where a cocoon of whitish silk is made preparatory to pupation. Cocoons in summer have been found in the cavity at the stem end of the fruit (Pl. 30, B), between fruits in contact, on or between mummified peaches, in leaves gummed to the twigs, or similar situations. It is probable that many larvæ find protected places on the twigs, in cracks, under bark scales on the trunk and branches, and in débris on the soil. During September larvæ were frequently observed making their way into the cracks in the bark of the trunk and larger limbs of the peach, evidently seeking winter quarters. Winter cocoons have been found in a few instances in little cavities eaten into the bark at the tips of injured twigs and more or less protected by the dried exuded gum and attached leaf fragments. The larvæ in general appear to be rather indiscriminate in their choice of pupation quarters and may be expected to choose any place on the trees where protection is afforded. Many larvæ have been collected under bands of burlap wrapped around the trunk and larger limbs of the trees. In the case of nursery stock the absence of rough bark and other protection on the young trees probably forces the larvæ to the ground, though a few individuals might find protection here and there on the plants. The insect hibernates in the full-grown larval condition in silken cocoons, pupation occurring in the spring. Owing to its manner of hibernating, the detection of the insect on nursery stock and young trees would be extremely difficult, and the disinfection of trees from the pest could be insured only by adequate fumigation with hydrocyanic-acid gas or other suitable substance.

EMERGENCE OF MOTHS AND NUMBER OF GENERATIONS.

Moths are out egg laying in the spring by the time the shoots of the peach are well out, as the work of the larvæ is in evidence when the shoots are 6 or 8 inches long. It would appear that there are two and probably three broods of larvæ each year, since injury begins early in the season, and larvæ in various stages of growth are to be found in late fall.

PLATE 26

Laspeyresia molesta:

A.—Injury to shoot of a Domestica plum.
B.—Injury by larva to cherry.

A
B

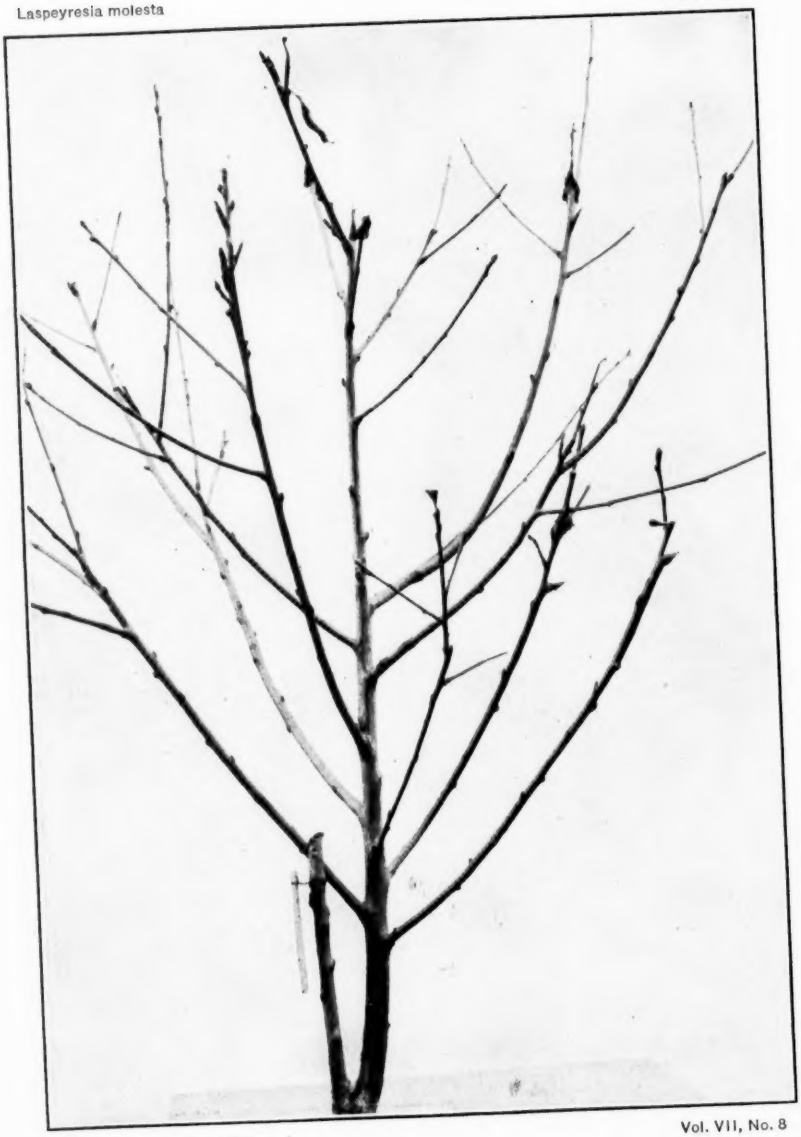


PLATE 27

Laspeyresia molesta:

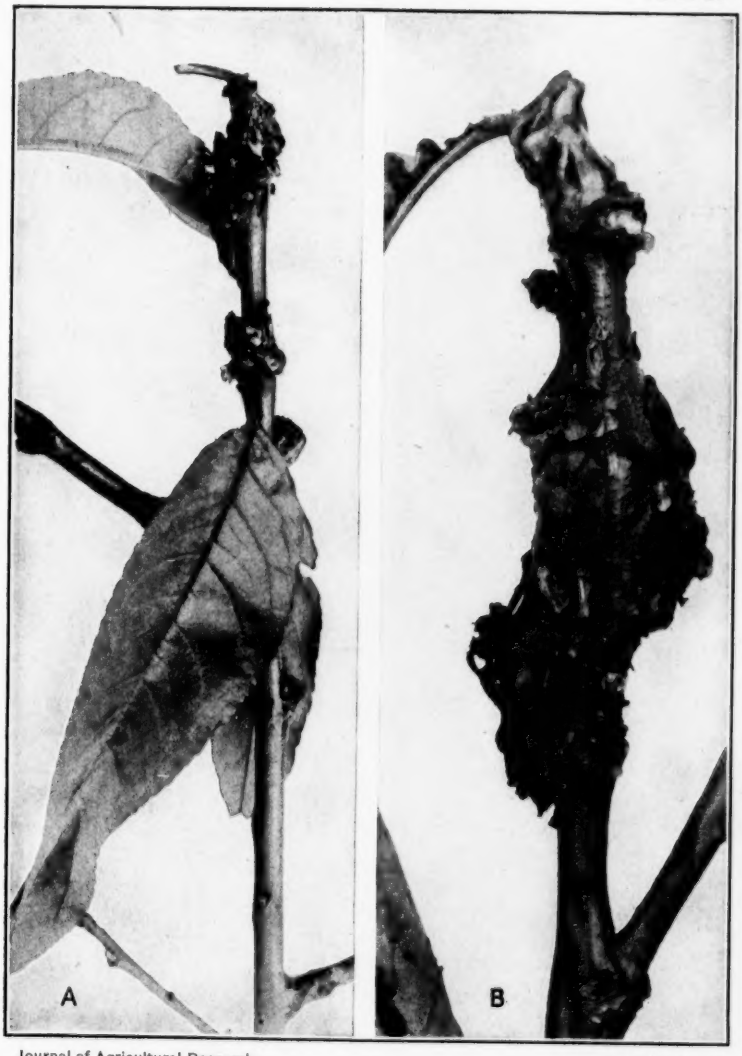
One-year budded peach nursery tree, showing injury of caterpillars.

PLATE 28

Laspeyresia molesta:

A.—Typical appearance of peach twigs in fall injured by larva.

B.—Peach twig, showing large mass of dried gum and leaf fragments due to attack by the caterpillar.


A
B

A
B

PLATE 29

Laspeyresia molesta:

A.—Typical exterior appearance of larval injury to peach shoot.
B.—The same shoot cut open, showing the larva in its burrow.

PLATE 30

Laspeyresia molesta:

A.—Cavity excavated in peach by larva entering at the side.
B.—Larval injury at stem end of peach; also the summer cocoon of the insect.

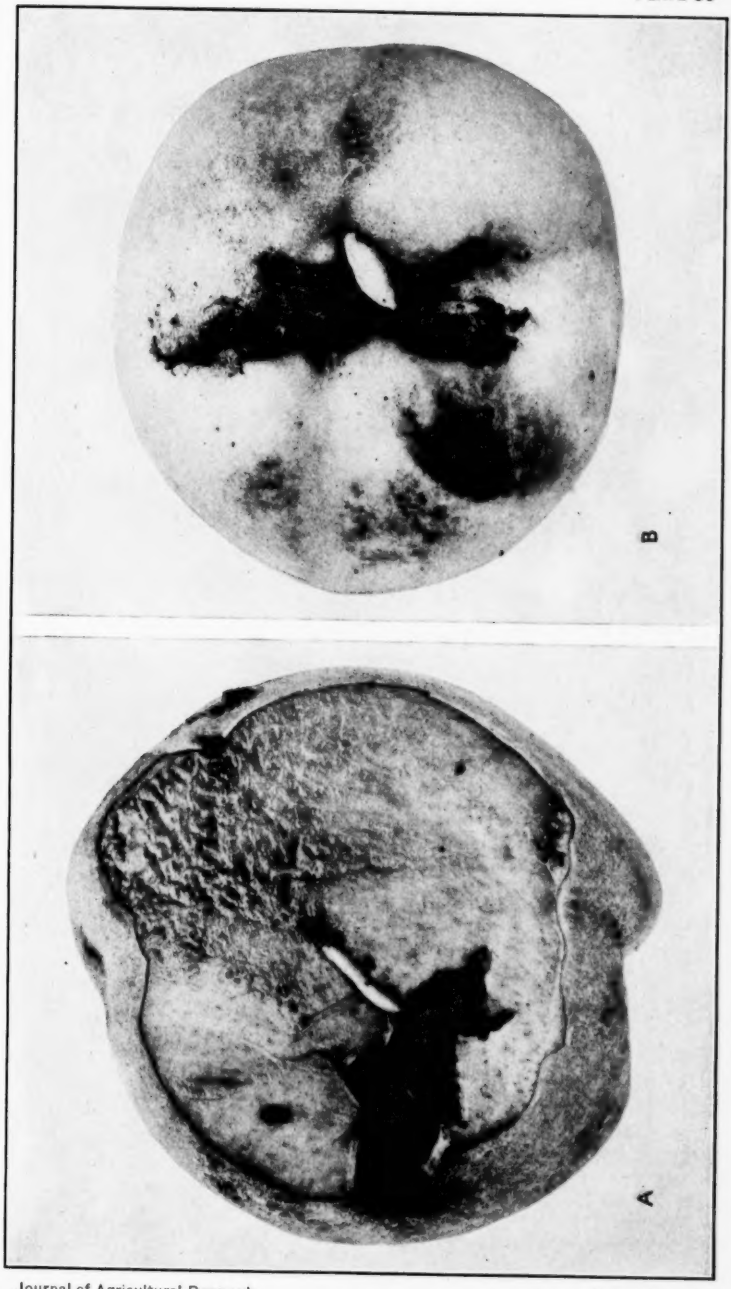

B
A

PLATE 31

Laspeyresia molesta:

Peach cut open to show larval injury at the pit.